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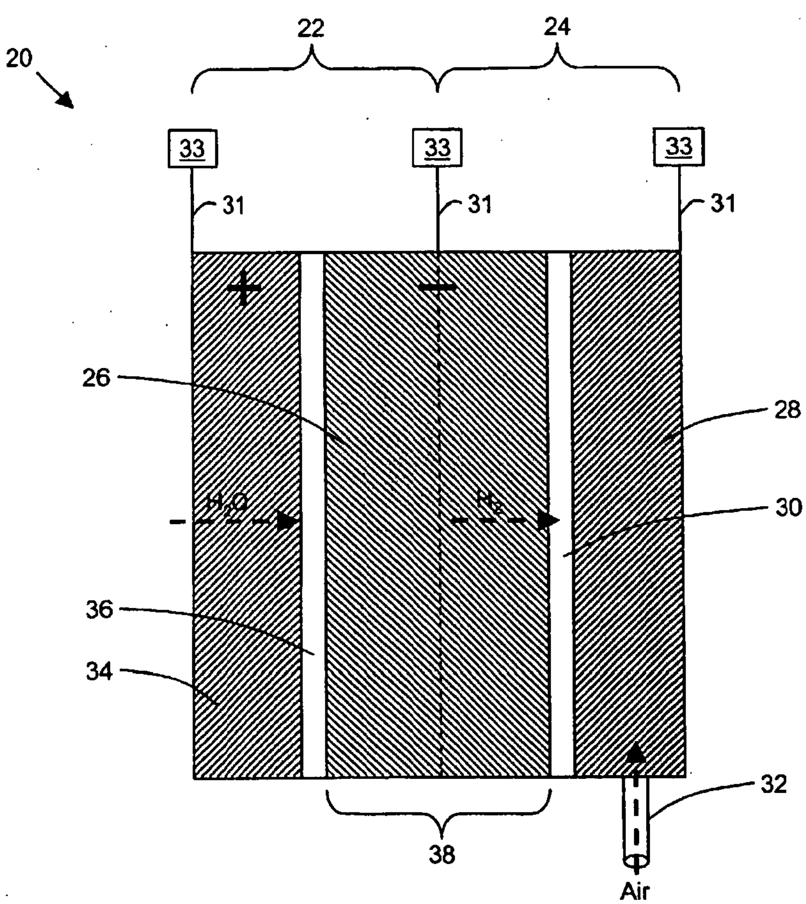
(54) Title: HYDROGEN STORAGE-BASED RECHARGEABLE FUEL CELL SYSTEM



(57) Abstract: An electrochemical system for converting electrical energy into chemical energy and chemical energy into electrical energy. The electrochemical system comprises a means for converting electrical energy into chemical energy, and a means for converting chemical energy into electrical energy, wherein the means for converting electrical energy into chemical energy and the means for converting chemical energy into electrical energy share a common electrode. In various embodiments, the present invention provides a hydrogen generator/fuel cell hybrid system. In various embodiments, the common electrode functions as a hydrogen source for the fuel cell, an active electrode for the hydrogen generator, and a portion or all of the common electrode is an anode of the fuel cell. Hydrogen, oxygen, and water may be recycled in the system.

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HYDROGEN STORAGE-BASED RECHARGEABLE FUEL CELL SYSTEM

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates generally to the field of fuel cell technology. More particularly, the present invention relates to a hybrid fuel cell system in which a hydrogen storage material operates as a solid-state hydrogen source for a fuel cell, as a fuel cell anode and as one active electrode for a hydrogen generator.

DESCRIPTION OF THE RELATED ART

Fuel cell technology has the potential to significantly reduce energy use and harmful emissions. Fuel cells are capable of efficient energy conversion, which can be used for both transportation and stationary applications. With respect to transportation applications, fuel cells represent a promising alternative to vehicles with conventional internal combustion engines, which burn fossil fuels such as gasoline or diesel. Internal combustion engines produce harmful particulates and add greenhouse gases to our atmosphere. Fuel cell vehicles, on the other hand, may be fueled with pure hydrogen and emit only water and energy in the form of electric power and heat. In addition, fuel cell vehicles may be twice as efficient as conventional vehicles. Internal combustion engines convert less than about 20 percent of the energy contained in gasoline into power that moves a vehicle. Hydrogen fuel cell powered vehicles are much more efficient, utilizing more than about 40 to about 50 percent of the fuel's energy. If a fuel cell is powered with pure hydrogen, it has the potential to be about 70 to about 80 percent efficient.

Typically, fuel cells create energy through a chemical process that converts hydrogen fuel and oxygen into water, producing electricity and heat in the process. Fuel cells operate very much like a battery with constantly renewed reactants. While batteries are recharged using electricity, fuels cells are recharged using hydrogen and oxygen. Conventional fuel cell vehicles may use pure hydrogen, hydrocarbon fuels or solid-state materials. A fuel cell stack uses the hydrogen supplied by the fuel source to

produce electricity to power one or more electric motors, which move the vehicle. A fuel cell stack may consist of hundreds of individual fuel cells. In many cases, a battery is used to store electricity produced by the fuel cell stack and by other systems in the vehicle, such as regenerative braking systems. The energy stored in the battery may also be used to power the electric motors as well as additional electrical systems in the vehicle. An air compressor may be used to supply oxygen from the environment. The amount of oxygen supplied to the fuel cell stack depends upon the amount of power needed by the vehicle. The amount of electricity produced by a fuel cell depends on how much hydrogen and air are supplied to it.

Unlike a battery, which is limited to the stored energy within, a fuel cell is capable of generating energy as long as the fuel is supplied. While battery electric vehicles use electricity from an external source stored in the battery, fuel cell vehicles create their own electricity. Fuel cells are also capable of providing a greater energy density or current density than conventional batteries for electric vehicles. This may allow fuel cell vehicles to be equipped with more sophisticated and powerful electronic systems than those found in current gasoline powered vehicles. For example, an increase in the number of control sensors in a vehicle may improve handling and braking systems, making vehicles safer.

Several approaches to fuel cell vehicle design focus on using hydrocarbon or alcohol fuels, such as methanol, natural gas and petroleum distillates. Vehicles utilizing these types of fuels require a reformer, which is operable for breaking down a hydrocarbon fuel into hydrogen for the fuel cell, carbon dioxide and water. The hydrogen produced by a reformer is not pure, which lowers the efficiency of the fuel cell. Adding a reformer to convert hydrocarbon fuel into hydrogen drops the overall efficiency of the fuel cell to about 30 to 40 percent. Although this system and internal combustion engines both produce carbon monoxide, the amount of carbon monoxide produced by the fuel cell is far less. In this system, for example, methanol from a fuel tank may be first exposed to a vaporizer, which produces vaporized methanol and steam. The vaporized methanol is then exposed to the reformer, which produces hydrogen, carbon dioxide and carbon monoxide. The fuel is then cleaned to produce hydrogen and carbon dioxide. The hydrogen is used by the fuel cell and the carbon

dioxide is released into the air. Disadvantages of using hydrocarbon fuels include: (1) onboard reformers which add to the complexity, cost and maintenance of the fuel cell system; (2) if the reformer allows carbon monoxide to reach the fuel cell anode, it will gradually decrease the performance of the cell; (3) reformers produce small amounts of greenhouse gases and other air pollutants; and (4) the transient operation of reformers.

There are many other challenges to be addressed regarding fuel cells, such as onboard hydrogen storage, safety, packaging efficiency, fuel recycling, supplying consumers with hydrogen, cold-weather operation, cost and public acceptance. Using current storage systems (e.g., compressed or liquid hydrogen), it is difficult to store enough hydrogen onboard a fuel cell vehicle to allow it to travel as far as a conventional vehicle on a full tank. Hydrogen gas is very diffuse and only a small weight amount can be stored in onboard fuel tanks of a reasonable size. This problem may be overcome by increasing the pressure under which the hydrogen is stored, but this solution raises safety issues and requires the use of additional pressurizing equipment, which increases costs, weight, packaging efficiency and safety concerns.

There exists a tremendous need in the art for overcoming the disadvantages described above. What is desired is a safe, efficient and low cost alternative to conventional internal combustion engines and fuel cell systems that employ hydrocarbon fuels as their fuel source. There exists a tremendous need for finding effective and efficient ways to constantly produce and store hydrogen in order to provide continuous operation. Still further, what is needed is a rechargeable fuel cell system that derives energy from an internal source and stores it within the system.

BRIEF SUMMARY OF THE INVENTION

In order to satisfy the needs addressed above, the present invention describes, in various embodiments, rechargeable hydrogen storage-based fuel cell systems. In various embodiments, novel designs of hydrogen generator/fuel cell hybrid systems are disclosed in which a hydrogen storage material possesses three functions: (1) a solid-state hydrogen source for a fuel cell component; (2) an active electrode for a

hydrogen-generating component; and (3) a portion or all of the electrode functions as an anode of the fuel cell component. By utilizing this design, a truly rechargeable fuel cell is realized. Also described in various embodiments, are hydrogen generator/fuel cell hybrid systems based on advanced solid-state fuel materials.

In various embodiments, the present invention provides an electrochemical system for converting electrical energy into chemical energy and chemical energy into electrical energy. The system comprises a means for converting electrical energy into chemical energy and a means for converting chemical energy into electrical energy. In one embodiment, the means for converting electrical energy into chemical energy is a solid-state hydrogen storage material and the means for converting chemical energy into electrical energy is a fuel cell. Hydrogen, oxygen, and water may be recycled in the system.

In various embodiments, advanced hydrogen storage materials (e.g. composite materials with improved hydrogen capacity) are used as a solid-state hydrogen source, and at the same time also serve as the fuel cell component anode electrode. With this system, a separate hydrogen source is not needed. Further, the hydrogen storage material functions as an active electrode for the hydrogen-generating component so that hydrogen can easily be recharged into the hydrogen storage material using water. Due to the multiple functionality of the hydrogen storage electrode, the packaging efficiency of the system is improved. In addition, system safety is improved by eliminating the use of compressed hydrogen gas and independent hydrogen storage component needs.

In one embodiment, advanced composite materials having improved hydrogen storage capacity may be employed, such as, but not limited to, metals, metal hydrides, conducting polymers, metal hydrides/carbon, other types of binary/ternary composites, nanocomposites, ceramics and organic hydrides. Conventional and novel solid-state fuel cell materials may be employed in the systems of the present invention. Solid-state fuel cell materials allow improved systems for electrochemically producing electrical power while overcoming limitations of conventional battery and fuel cell technologies.

In another embodiment, the present invention provides electrochemical systems that provide improved performance parameters, such as improved energy density, decreased recharge times and reduced safety concerns because of the use of solid-state fuels.

In a still further embodiment, the present invention provides electrochemical systems having improved design flexibility that may be employed in transportation applications, residential applications, commercial and industrial facilities, and large-scale power generation applications.

In a still further embodiment, a fuel cell component of the present invention is an electrochemical device comprising one or more pairs of spaced anode and cathode plates, an electrolyte disposed between the plates, and an air delivery means to deliver air to the one or more cathode plates. The fuel cell operates to convert the free energy of the chemical reaction generated by and between the chemically reactive materials that make up the cells, into electrical energy. In various embodiments, the anode comprises solid-state hydrogen storage materials, and the cathode comprises a porous structure into which air is effectively supplied as an oxidant.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the systems of the present invention are better understood when the following Detailed Description of the Invention is read with reference to the accompanying drawings, wherein:

FIG. 1 is a schematic diagram of an electrochemical system for converting electrical energy into chemical energy and chemical energy into electrical energy in accordance with an exemplary embodiment of the present invention;

FIG. 2 is an illustration of reactions for recharging a solid-state hydrogen storage material in accordance with an exemplary embodiment of the present invention;

FIG. 3 is an illustration of the recharging of a metal hydride hydrogen storage material in accordance with an exemplary embodiment of the present invention; and

FIG. 4 is a schematic diagram of the electrochemical system of FIG. 1 deployed in a transportation application in accordance with an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

As required, detailed embodiments of the present invention are disclosed herein, however, it is to be understood that the disclosed embodiments are merely exemplary of the invention that may be embodied in various and alternative forms. Specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims as a representative basis for teaching one skilled in the art to variously employ the present invention. Throughout the drawings, like elements are given like numerals. The electrochemical system described below applies to power generation in general, transportation applications, portable power sources, home and commercial power generation, large power generation and any other application that would benefit from the use of such a system.

Referring now to FIG. 1, shown generally at 20, is one embodiment of an electrochemical system comprising a fuel cell/hydrogen generator hybrid design. The electrochemical system is operable for converting electrical energy into chemical energy, and chemical energy into electrical energy. The system comprises a means for converting electrical energy into chemical energy and a means for converting chemical energy into electrical energy. In one embodiment, the means for converting electrical energy into chemical energy is a solid-state hydrogen storage material and the means for converting chemical energy into electrical energy is a fuel cell. Hydrogen can be recycled in the system.

The electrochemical system 20 comprises a hydrogen generator component 22 and a fuel cell component 24, the components being structurally and operationally connected via a common electrode. The fuel cell component 24 comprises an anode, which is the negative electrode 26, and a fuel cell cathode 28, which is the positive electrode. The anode and cathode may be separated from one another by a fuel cell membrane, such as a proton exchange membrane (PEM) 30. Although the fuel cell

structure and materials may vary, the fuel cell component 24 is a galvanic energy conversion device that chemically combines hydrogen and an oxidant within catalytic confines to produce a DC electrical output. In one form of the fuel cell, the fuel cell cathode 28 and materials define passageways for the oxidant, and the negative electrode 26 and materials define the passageways for the fuel. The fuel cell cathode 28 is preferably a micro-porous structure through which liquids will not readily or freely flow, but in and through which oxygen, under pressure, can be fed to support the chemical reaction within the fuel cell component 24. A gas containing oxygen may be fed into the fuel cell cathode 28 through a cathode supply line 32. In one embodiment, ambient air may be the source of the oxygen.

The proton exchange membrane 30 (electrolyte) separates the fuel cell cathode 28 and negative electrode 26 materials. The proton exchange membrane 30 conducts positively charged ions while blocking electrons. Fuel cells employing a proton exchange membrane 30 operate at relatively low temperatures, such as about 100°C due to the limitations imposed by the thermal properties of the membrane materials. PEM 30 fuel cells also possess a high power density, can vary their output quickly to meet shifts in power demand, and are suited for applications in which a quick start-up is required. The anode 26 and cathode 28 provide internal flow paths for electrical current within the fuel cell component 24 to a plurality of current collectors 31, which in turn connect to one or more external loads 33. During the fuel cell component 24 operation, electrons created by the dissociation of hydrogen molecules and atoms, due to the action of the catalyst, are available and are sent via the current collectors 31 to the one or more external loads 33. The operating voltage across an individual cell of the fuel cell component 24 may be on the order of about 1 volt, maximum. Therefore, a plurality of individual cells may be placed in series or in parallel in order to obtain an adequate load voltage, as is described in more detail below. The layers of the fuel cell component 24 are conductive, either electronically or ionically, including the anode 26, the electrolyte 30 and the cathode 28.

The fuel cell component 24 provides a DC voltage used to power one or more electric motors or any additional electrical components or systems. The fuel cell component 24 of the present invention derives hydrogen from a solid-state material and water, or

other hydrogen source. The negative electrode 26 of the fuel cell component 24, the anode, is operable for conducting electrons freed from the solid-state hydrogen storage material so that they can be supplied to the current collectors 31. The negative electrode 26 may comprise channels etched into its surface operable for dispersing hydrogen equally over the surface of a catalyst of the proton exchange membrane 30. The fuel cell cathode 28 may also comprise channels etched into its surface operable for distributing oxygen to the surface of the catalyst of the proton exchange membrane 30. The fuel cell cathode 28 is further operable for conducting electrons back from an external circuit to the catalyst, where they recombine with hydrogen ions and oxygen to form water. The catalyst is operable for facilitating the reaction between hydrogen and oxygen. The catalyst may comprise materials including, but not limited to, platinum, palladium and ruthenium, which faces the proton exchange membrane 30. The surface of the platinum is such that a maximum amount of the surface area is exposed to the hydrogen or oxygen. Oxygen molecules are dissociated into oxygen atoms in the presence of the catalyst and accept electrons from the external circuit while reacting with hydrogen, thus forming water. In this electrochemical reaction, a potential develops between the two electrodes.

The hydrogen-generating component 22 of the hybrid system provides energy storage capacity and shares the electrode 26 of the fuel cell component 24. The hydrogen-generating component 22 further comprises electrode 34 and separator 36. The structure of the hydrogen-generating component 22 is typically a construction including one or more identical cells, with each cell comprising electrode 34, electrode 26 and separator 36. Electrode 26 comprises hydrogen storage material 38 and performs multiple functions: (1) a solid-state hydrogen source for the fuel cell component 24; (2) an active electrode 26 for the hydrogen-generating component 22; and (3) a portion or all of the electrode functions as an anode of the fuel cell component 24.

The electrochemical hydrogen-generating component 22 has storage characteristics characterized by being capable of accepting direct-current (DC) electrical energy in a charging phase to return the solid-state material to a hydrogen-rich form, retaining the energy in the form of chemical energy in the charge retention phase, and releasing

stored energy upon a demand by the fuel cell component 24 in a discharge phase. The hydrogen-generating component 22 is able to repeatedly performing these three phases over a reasonable life cycle based on its rechargeable properties. The electrical energy may be supplied from an external source, a regenerative braking system, as well as any other source capable of supplying electrical energy. The solid-state material may be recharged with hydrogen by applying the external voltage. By utilizing this design, a truly rechargeable fuel cell is realized without the need for a separate hydrogen source.

One difference between the fuel cell component 24 and the hydrogen-generating component 22 is that the hydrogen-generating component 22 possess only a limited amount of stored energy until recharged, whereas the fuel cell component 24 will continue to produce electrical power output as long as a fuel and oxidant are supplied thereto.

Hydrogen and oxygen are required by the fuel cell component to produce electrical energy. Hydrogen contains more chemical energy per weight than any hydrocarbon fuel. The electrochemical system 20 of the present invention is operated with solid-state materials capable of hydrogen storage, such as, but not limited to, conductive polymers, ceramics, metals, metal hydrides, organic hydrides, a binary or other types of binary/ternary composites, nanocomposites, carbon nanostructures, hydride slurries and any other advanced composite material having hydrogen storage capacity. Conventional and novel solid-state fuels may be employed in the practice of the present invention as the common electrode 26.

Solid-state hydrogen storage materials provide substantial improvements in energy density and are ideal for transportation applications. Unlike conventional hydrogen-oxygen fuel cells that require refilling of the hydrogen fuel, the fuel of a present invention is recoverable by electrical recharging and supplying water. The fuel of the present invention is also in a solid-state, making it safe to handle and store. The solid-state fuel has two simultaneous functions, energy storage and energy generation. Therefore, the hybrid system can recharge and provide the hydrogen fuel simultaneously, and the output power density is dependent on its energy storage

capacity. In other words, the generation of electrical power is coupled to the storage of energy.

The solid-state materials suitable for use in the practice of the present invention should be able to absorb large amounts of hydrogen, and the material should also maintain a high-degree of structural integrity and good hydrogen absorption characteristics over multiple charge/discharge cycles. In other words, the structural integrity should not affect capacity and the solid-state material should exhibit high stability over multiple cycles of hydrogen absorption.

As stated above, various solid-state materials may be employed in the practice of the present invention. In one example, metal hydrides have been found to be useful in the hydrogen generation and storage systems of the present invention. The metal hydride material may provide multiple functions: (1) a solid-state hydrogen source for the fuel cell component 24; (2) an active electrode 26 for the hydrogen-generating component 22; and (3) a portion or all of the electrode functions as an anode of the fuel cell component 24. The metal hydrides may have the general chemical formula M_xH_y where M is a metal, examples of which include nickel, magnesium, aluminum, lithium, boron, zirconium and titanium. H is hydrogen. Examples of metal hydrides to be used in accordance with the present invention include, but are not limited to, $LaNi_5$, FeTi, FeTiMn, $ZrMn_2$, Ti, WO_3, V_2O_5, $NaAlH_4$, $LiBH_4$, and mixtures thereof. The volumetric hydrogen density of a solid such as a metal hydride is fairly high, making it a compact storage medium. Further, by binding the hydrogen as a solid, hydrogen is prevented from desorbing unless heat is applied, thereby improving safety.

Adding or removing heat is necessary to absorb or desorb hydrogen. Hydrogen generation may be controlled by either contacting heat with, or separating the heat from, the solid-state hydrogen-rich material. A heating/cooling channel may be provided for adding/removing heat to/from a structure containing the solid-state material. A heat-transferring surface may be disposed adjacent to the solid-state material housing to provide good thermal conductivity. When the fuel cell component 24 places a demand on the electrochemical system 20 for hydrogen, heat

may be applied to the hydrogen storage material. The evolution of hydrogen may be controlled in a pressurized set-up. Hydrogen evolution may not be favored when the pressure of hydrogen above the negative electrode 26 is high.

Hydrides typically store about 1 to about 7 percent hydrogen by weight and have high volumetric storage densities, higher than liquid or solid hydrogen. In hydrogen absorption by the solid-state material, under pressure, hydrides absorb hydrogen and release heat. The stored hydrogen is released from the solid-state material when the pressure is reduced and the heat is applied. Solid-state storage materials may be chosen based upon weight, hydrogen capacity, rate of hydrogen absorption/desorption, temperature of hydriding/dehydriding, pressure of hydriding/dehydriding, and cyclic stability.

Referring to FIG. 2, two electrochemical reactions take place in the hydrogen-generating component 22 of the hybrid system 20, one at the anode 26 and one at the cathode 34. The overall reaction is illustrated at Block 40. At the electrode of the hydrogen-generating component 22 (anode 26) electrons are combined with hydrogen and a reactive group (*R*) to form a recharged hydrogen storage material (Block 42). At the other electrode (cathode 34), water is split into oxygen gas and protons, which are transported across a proton-conducting electrolyte (Block 44). The reactions illustrated in FIG. 2 are recharging reactions of the hydrogen storage material. The recharging reactions convert electrical energy into chemical energy.

Oxygen may be liberated in excess during the recharging phase. The oxygen may be let out into the atmosphere or recycled into the fuel cell component 22 where it combines with hydrogen to form water. Recharging of the hybrid system 20 results in the production of both water and oxygen, which may be recycled. The electrochemical system 20 may require cooling and management of the exhaust water in order to function properly. The water produced by the fuel cell component 24 may be recycled, through a storage tank, back into the hydrogen-generating component 22, where it is used to recharge the solid-state fuel, along with electricity. The heat produced by the fuel cell component 24 may be adequate for only limited usage. The only liquid present in the hybrid system is water, thus limiting component corrosion

problems. Water management in the proton exchange membrane 30 is critical for efficient performance. Because the membrane 30 must be hydrated, the fuel cell component 24 must operate under conditions where the water by-product does not evaporate faster than it is produced.

By utilizing a solid-state hydrogen storage material and a rechargeable system 20, as opposed to hydrogen or gas, it is not necessary to store large amounts of fuel within the electrochemical system 20. Water may be added to the system 20 if needed, and hydrogen, oxygen and water may be recycled. The system performance relies on the materials used. Hydrogen is released during operation when a demand is placed upon the system 20, consumed by the means for converting chemical energy into electrical energy (e.g., the fuel cell component 24), and then the system 20 is charged by supplying water and electrical energy to the hydrogen-generating component 22. The system 20 operates similar to a battery system with constantly renewed reactants. The electrochemical system 20 may also be recharged while power is drawn from the system 20.

Referring to FIG. 3, a metal hydride is one example of a potential solid-state hydrogen storage material. For the conversion of electrical energy to chemical energy, two electrochemical reactions take place in the hydrogen-generating component 22 of the hybrid system 20, one at the anode 26 and one at the cathode 34. The overall reaction is illustrated at Block 50. In an acidic case, at the metal hydride electrode (cathode 34), electrons are combined with hydrogen and a metal to form a metal hydride (Block 52). At the other electrode (anode 26), water is split into oxygen gas and protons, which are transported across a proton-conducting electrolyte (Block 54). The reactions illustrated in FIG. 3 are recharging reactions for metals. If a metal hydride is the solid-state material, the fuel cell component 22 consumes the released hydrogen from the metal hydride leaving behind the metal at the electrode. In recharging operations an electrochemical reaction takes place, during fuel cell operation a chemical release takes place. The hydrogen may be used and depleted by fuel cell operation, which results in more hydrogen to be evolved from the metal hydride. When the hydrogen is consumed and only the metal is left, water and a voltage are used to recharge it back to a metal hydride.

Water has been described above as the source of hydrogen, however, water is not meant to be a limiting example of the present invention. In other examples, sources for hydrogen may include methanol, sodium borohydride, cyclohexanol and phenyl amine, among others.

Referring to FIG. 4, in a non-limiting example, the electrochemical system 20 of the present invention may be employed in transportation applications. The chemical energy to electrical energy converting means (e.g., fuel cell component 24) may be constructed either as separate individual cells, or as a fuel cell stack. In stack construction, a predetermined number of individual cells are incorporated one after the other, in order to provide a correspondingly higher output voltage. In one example, a fuel cell stack may comprise several hundred individual cells. By connecting many cells in parallel or in series to form the stack, potentials and currents can be produced that are sufficient to drive a vehicle. A series connection may be accomplished between adjacent cells using an interconnect material that isolates the fuel and oxidant gases from one another, while electronically connecting the anode 26 of one cell to the cathode 28 of an adjoining cell. Typically, a fuel cell only produces about 1 volt of electricity per cell, which is not enough to effectively power the vehicle by itself. The stack can be used to increase the total voltage output, producing enough energy to sufficiently power the vehicle.

By structurally linking the fuel cell stack with the electrical energy to chemical energy converting means (e.g., hydrogen-generating component 22), improved design flexibility is achieved. By eliminating separate hydrogen storage component needs, safety and reliability are improved. Water is one example of a hydrogen source and may be stored in a water storage tank 60 as a liquid. A sufficient quantity of water may be stored to provide an adequate amount of hydrogen to give the vehicle a suitable driving range. Water produced by the fuel cell component 24 may be stored in the storage tank 60 and recycled to the hydrogen-generating component 22.

An air compressor unit 62 may be used to supply the oxidant from the ambient environment to the cathode 28 of the fuel cell component 24. The amount of electricity produced by the fuel cell stack depends on how much hydrogen and air is

supplied to it. The air compressor unit 62 is operable for controlling the rate at which air is supplied to the fuel stack according to a demand for power. A fuel cell vehicle may be powered by one or more electric motors 64. In one example, an electric motor may be used to power each wheel of an automobile. A control module 66 may be used to control the fuel cell/hydrogen generator electrochemical system 20, the water storage tank 60, the air compressor unit 62, the one or more electric motors 64 and any additional components and systems.

The fuel cell component 22 is used to convert chemical energy into electrical energy which is used to drive the vehicle. When the vehicle is not in operation, electrical energy is supplied to recharge the solid-state hydrogen storage material so that the vehicle can be driven again. The electrochemical system 20 of the present invention exhibits high-rate discharge capabilities, fast charging and adequate voltage compatibilities.

It is apparent that there has been provided, in accordance with the system of the present invention, a electrochemical system for converting electrical energy into chemical energy and chemical energy into electrical energy, while recycling hydrogen. Although the system of the present invention has been described with reference to preferred embodiments and examples thereof, other embodiments and examples may perform similar functions and/or achieve similar results. All such equivalent embodiments and examples are within the spirit and scope of the present invention and are intended to be covered by the following claims.

WHAT IS CLAIMED IS:

1.An electrochemical system for converting electrical energy into chemical energy and chemical energy into electrical energy, comprising:

a first conversion system for converting electrical energy into chemical energy; and

a second conversion system for converting chemical energy into electrical energy;

wherein the first conversion system and the second conversion system share a common electrode.

2.The system of claim 1, wherein the common electrode is a hydrogen storage material.

3.The system of claim 2, wherein the hydrogen storage material is at least one of a conductive polymer, a ceramic, a metal, a metal hydride, an organic hydride, a binary composite, a binary-ternary composite, a nanocomposite, a carbon nanostructure and a hydride slurry.

4.The system of claim 1, wherein the common electrode is a hydrogen source for the second conversion system, an active electrode for the first conversion system, and a portion or all of the common electrode is an anode of the second conversion system.

5.The system of claim 1, wherein hydrogen, oxygen and water are recycled in the system.

6.The system of claim 1, wherein the first conversion system is operable for accepting electrical energy in a charging phase, retaining energy in the form of chemical energy in a charge retention phase, and releasing stored energy in a discharge phase upon a demand by the means for converting chemical energy into electrical energy.

7.The system of claim 6, wherein the electrical energy accepted in the charging phase is supplied by an internal voltage source, an external voltage source, or a regenerative braking system.

8.The system of claim 1, wherein the electrochemical system may be employed in transportation applications, residential applications, commercial and industrial facilities, and large-scale power generation applications.

9.An electrochemical system for converting electrical energy into chemical energy and chemical energy into electrical energy, comprising:

a hydrogen generator operable for converting electrical energy into chemical energy; and

a fuel cell operable for converting chemical energy into electrical energy;

wherein the hydrogen generator and the fuel cell share a common electrode; and

wherein hydrogen can be recycled in the electrochemical system.

10.The system of claim 9, wherein the common electrode is a solid-state hydrogen storage material.

11.The system of claim 10, wherein the solid-state hydrogen material is at least one of a conductive polymer, a ceramic, a metal, a metal hydride, an organic hydride, a binary composite, a binary-ternary composite, a nanocomposite and a carbon nanostructure.

12.The system of claim 9, wherein the common electrode is a solid-state hydrogen source for the fuel cell, an active electrode for the hydrogen generator, and a portion or all of the common electrode is an anode of the fuel cell.

13.The system of claim 9, wherein the hydrogen generator accepts electrical energy in a charging phase to return the hydrogen generator to a hydrogen-rich form, retaining the energy in the form of chemical energy in a charge retention phase, and releasing stored energy in a discharge phase upon a demand by the fuel cell.

14.The system of claim 9, wherein the only liquid in the system is water.

15.The system of claim 9, wherein the hydrogen generator is recharged using water and a voltage.

16.The system of claim 9, wherein the electrochemical system may be employed in transportation applications, residential applications, commercial and industrial facilities, and large-scale power generation applications.

17.A power generator, comprising;

a hydrogen generator operable for converting electrical energy into chemical energy;

a fuel cell operable for converting chemical energy into electrical energy; and

a common electrode for the hydrogen generator and the fuel cell; and

wherein the common electrode is a solid-state hydrogen source for the fuel cell, an active electrode for the hydrogen generator, and an anode of the fuel cell.

18.The power generator of claim 17, wherein the common electrode is a solid-state hydrogen storage material.

19.The power generator of claim 17, wherein the hydrogen generator accepts electrical energy in a charging phase to return the hydrogen generator to a hydrogen-rich form, retaining the energy in the form of chemical energy in a charge retention phase, and releasing stored energy in a discharge phase upon a demand by the fuel cell.

20.The power generator of claim 17, wherein the hydrogen generator is recharged using water and a voltage.

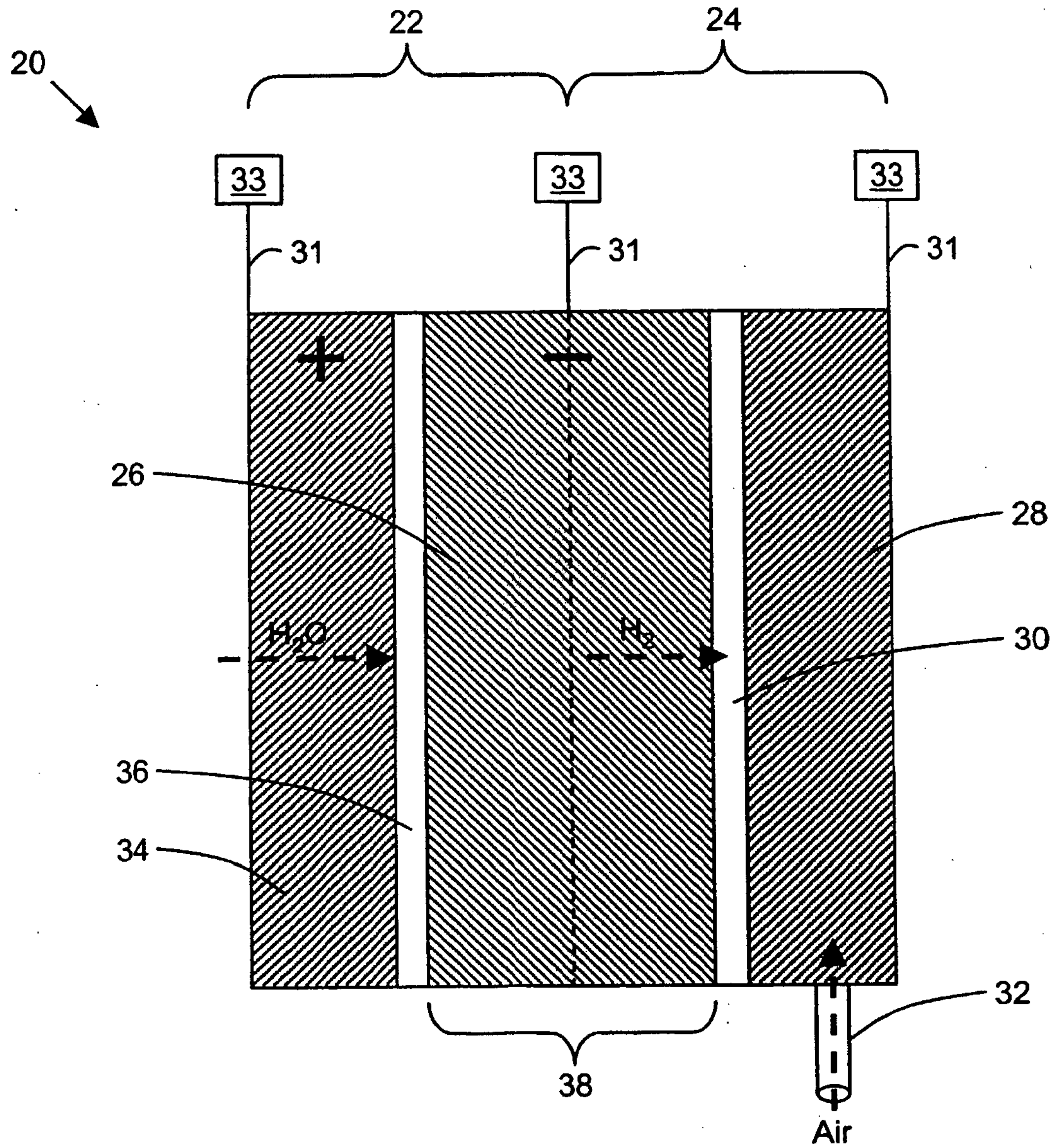

FIG. 1

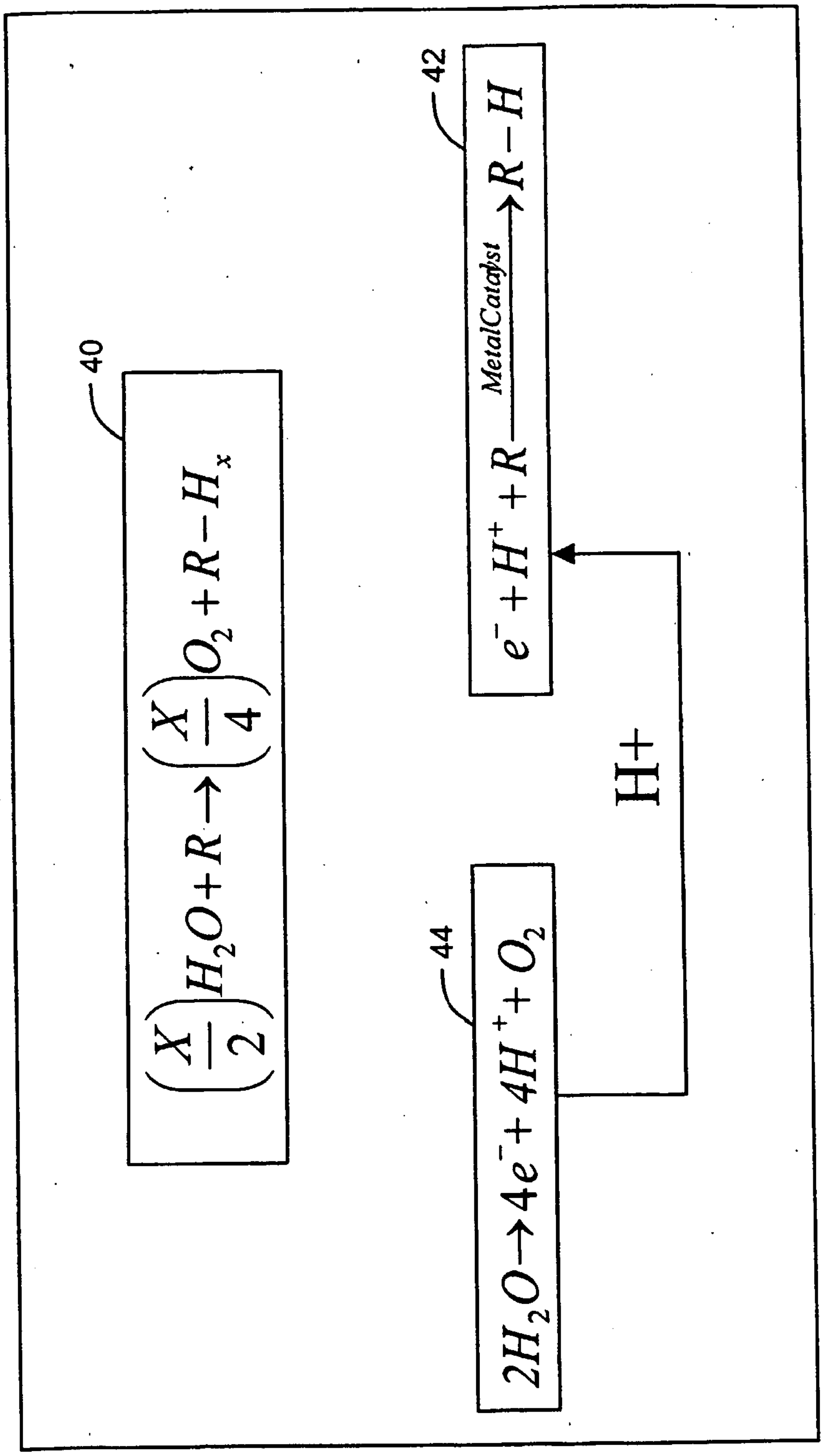
40
$\left(\frac{X}{2}\right)H_2O + R \rightarrow \left(\frac{X}{4}\right)O_2 + R - H_x$
42
$e^- + H^+ + R \xrightarrow{MetalCatalyst} R - H$
H+
44
$2H_2O \rightarrow 4e^- + 4H^+ + O_2$

FIG. 2

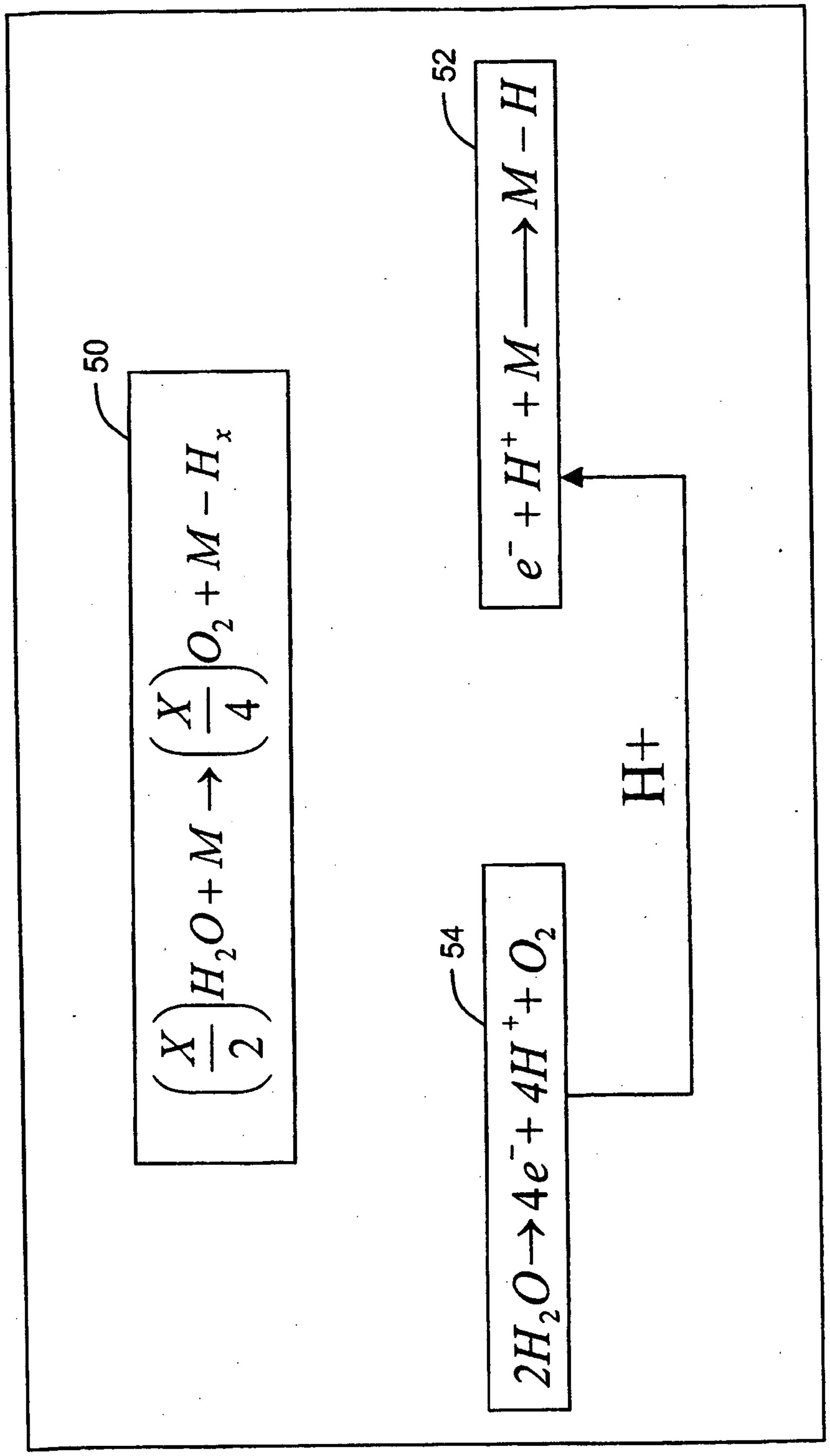
50
$\left(\frac{X}{2}\right)H_2O + M \rightarrow \left(\frac{X}{4}\right)O_2 + M - H_x$
52
$e^- + H^+ + M \longrightarrow M - H$
H+
54
$2H_2O \rightarrow 4e^- + 4H^+ + O_2$

FIG. 3

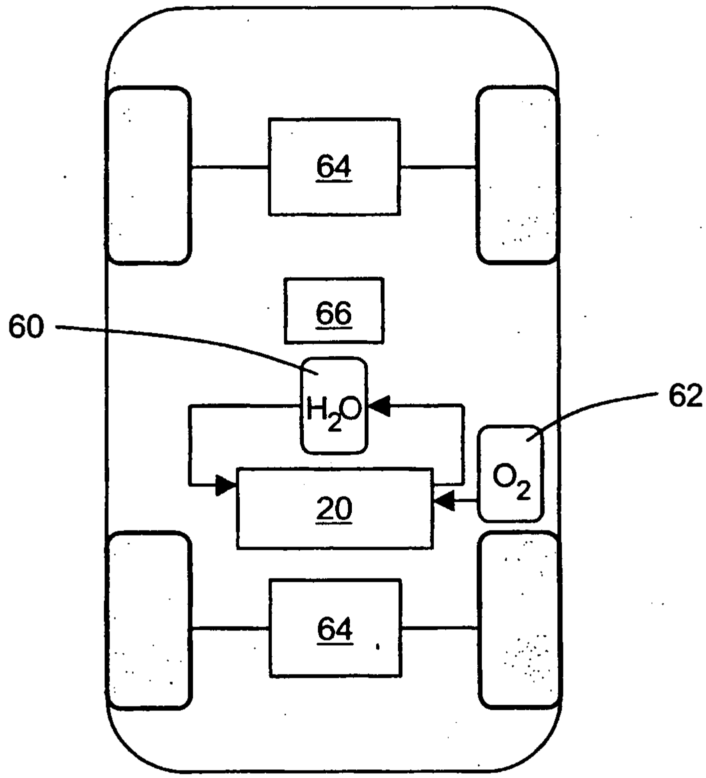

FIG. 4

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